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Direct Current Corona on a Wire at the Axis of a Short Cylinder

Electrical Engineering

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DIRECT CURRENT CORONA ON A WIRE AT THE AXIS OF A SHORT CYLINDER

BY

LESLIE WILLIAM FAULKNER

B.S. University of Illinois, 1914

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

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IN ELECTRICAL ENGINEERING

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

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THE GRADUATE SCHOOL

June 5, 1915

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Leslie William Faulkner

ENTITLED Direct Current Corona on a Wire at the Axis of a Short Cylinder

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Electrical Engineering

Jakob Kunz
In Charge of Thesis

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Recommendation concurred in:*

Committee
on
Final Examination*

*Required for doctor's degree but not for master's.

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DIRECT CURRENT CORONA ON A WIRE AT THE AXIS OF A SHORT CYLINDER.

I. OBJECT OF THE INVESTIGATION

This phase of the corona problem was undertaken to determine the magnitude of, and the process by which losses occur in high voltage transformer bushings, in wall, ceiling and line insulators. In order to obtain a basis from which to attack this problem in the laboratory, it was necessary to start with air as the insulating medium and to use a wire passing through the axis of a short cylinder so as to obtain the conditions involved in a wire passing through an insulator which in turn is surrounded by some type of conductor.

II. DESCRIPTION OF THE APPARATUS.

For a source of power a battery thirty G.E.D.C. self-excited generators were connected in series. Each machine being rated;amperes, 0.5; volts, 500; watts, 250; speed, 1700 r.p.m.

These machines were arranged in two sets, one of ten machines and the other of twenty, so that either or both sets could be used to obtain the required voltage. The voltage was controlled by closing the field circuit of the generators themselves, by varying the speed of the driving motors or by a rheostat in the field of one of the generators.

Fig. 1 shows the scheme of connection. The short arc was made of a plane and point mounted on a hard rubber

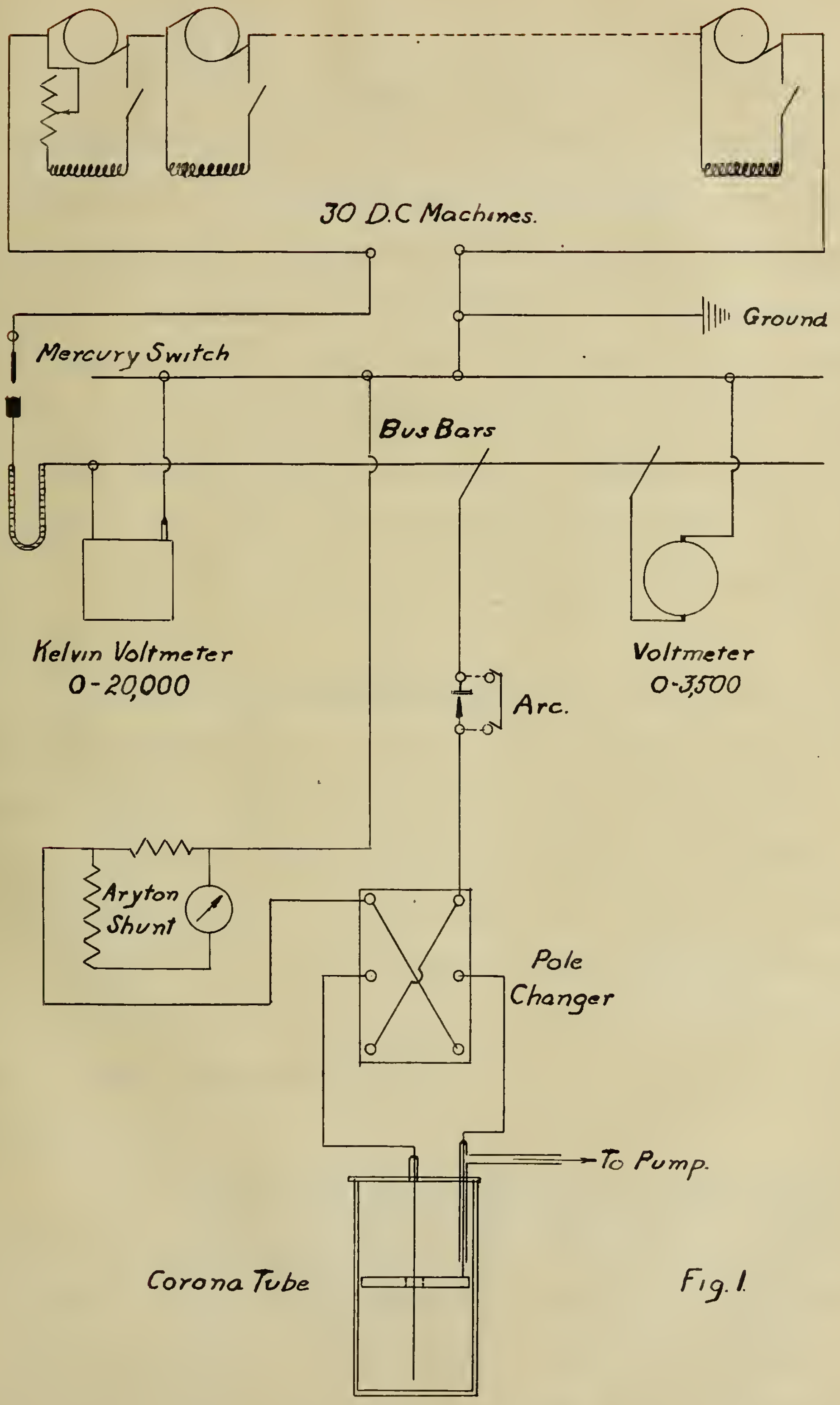
30 D.C Machines.
Ground
Mercury Switch
Bus Bars
Kelvin Voltmeter
0-20,000
Voltmeter
0-3,500
Arc.
Aryton
Shunt
Pole
Changer
To Pump.
Corona Tube

Fig. I.

base, the point being the adjustable electrode. Provisions were made whereby the arc could be put into or taken out of the circuit without disturbing any of the other previously existing conditions. Extreme care was taken in setting up the battery of machines, the switchboard and the corona circuits to have the whole thoroughly insulated from the ground, so as to prevent disturbances and minimize the danger from shock. Arrangements were also made for changing the polarity of the machines at will, and thus reverse the polarity of the bus-bars. One of the bus-bars was permanently connected to earth.

The voltage between bus-bars was measured by two electrostatic voltmeters. For the lower ranges of potentials a Max Kohl 0-3500, voltmeter was used, and for the higher potentials a vertical type Kelvin electrostatic voltmeter, constructed in the shop of the laboratory, having two ranges of 1500 - 10,000, and 1500 - 20,000 volts; depending upon the weight on the moving element. Both the Kohl and the Kelvin voltmeters were calibrated by a specially designed attracted disk electrometer.

The current flow due to corona was measured by a D'Arsonval galvanometer of 849.5 ohms resistance. The "Figure of Merit" of the galvanometer was 8.25 x 10^{-9} amp. per m.m. scale deflection. The voltage of the dry cell used in obtaining the "Figure of Merit" was measured by an accurate

voltmeter in the calibration room of the laboratory.

The corona apparatus is shown in Fig. 2. The glass joints being ground to fit and sealed with wax so that a vacuum could be maintained without difficulty and also so that the apparatus could be easily dismantled and changes made. The ground joint, A, was lubricated with a rubber compound so that it could be removed without heating the glass; thus facilitating the replacement of wires in the tube. The wire being hung from a platinum hook a' and held taught by the weight w. The oil, O, in the bottom of the tube was for the purpose of damping the oscillations of the wire and weight. The aluminum disc, D, was 2 m.m. thick, and had a round hole of 16 m.m. radius at its center. To this disc there was riveted a heavy round copper wire which pressed against the helical spring contact in the exhaust tube E. The short cylinder with its heavy wall, or disc as it shall be called, was supported by glass rod pins projecting from the three vertical hard rubber rods R. The brass plate B, with three screws in it at the vertices of an equilateral triangle served as a means for adjusting the position of the wire in the hole through the disc.

III. METHOD OF TAKING DATA.

In order to maintain dry air in the corona tube for the different series of pressures, the tube was exhausted three times to a pressure of 10 m.m. of mercury, each time bringing the pressure back to atmospheric by admitting air through a tube

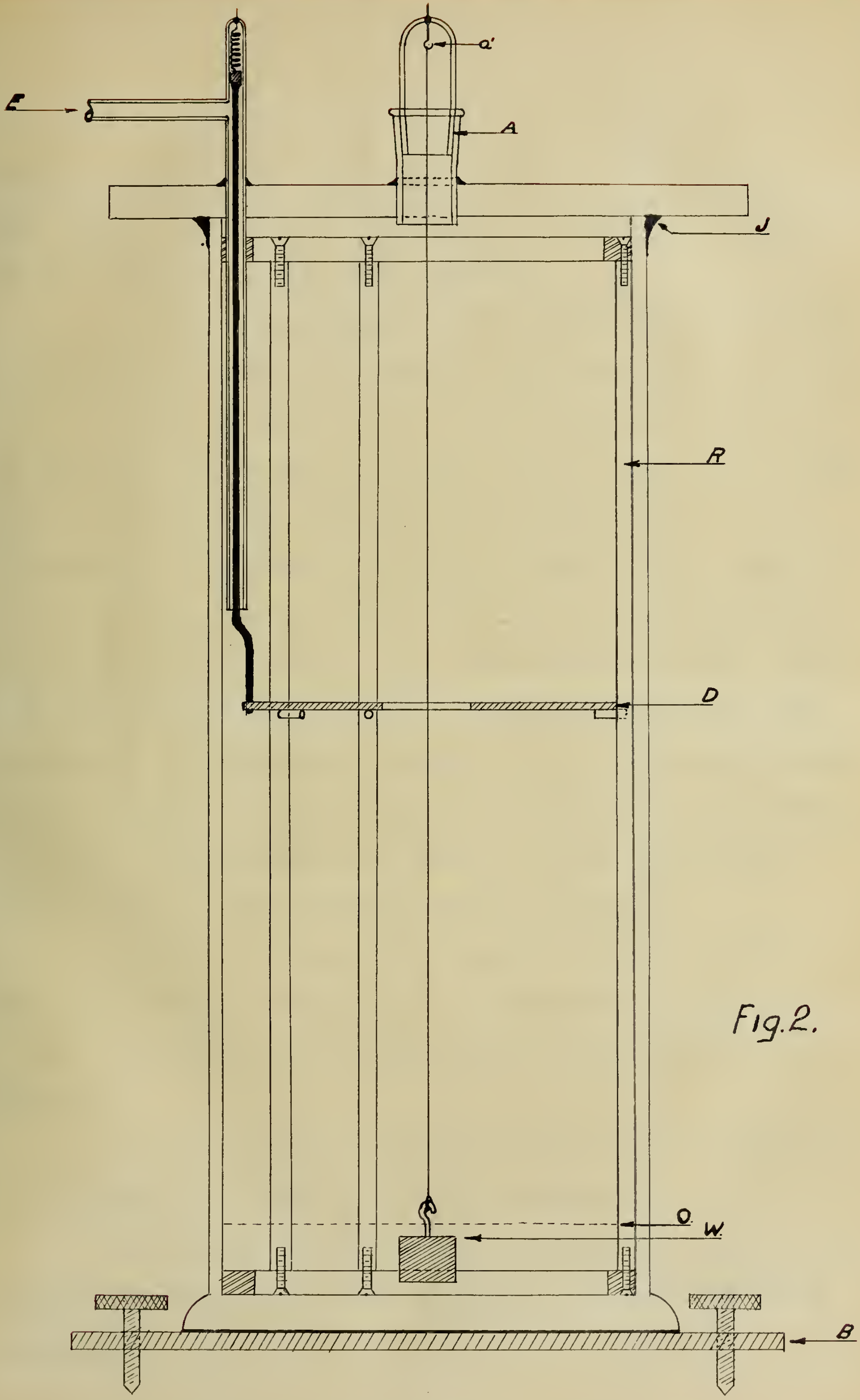

Fig.2.

filled with $CaCO_3$ and a bubbling bottle containing H_2SO_4. After the air was dried in this manner the pressure in the tube was adjusted to the value desired.

The wire was centered with respect to the hole in the disc, by the levelling screws in the base plate of the tube.

With the wire positive, and a definite pressure in the tube the voltage was increased from 500 volts until a deflection of more than four millimeters was observed in the galvanometer. The reason for this proceedure being, that Farwell found the positive corona for a wire of the size used in this investigation started before the negative corona, and as there was always a jump of two or three millimeters in the galvanometer on closing the corona circuit before the voltage was high enough to produce a constant deflection, the voltages and current readings were not recorded before more than a four millimeter steady deflection was observed.

After the first steady deflection of the galvanometer was observed the lights in the room were extinguished so that the nature of the corona would be more easily discernible.

The polarity of the wire was next reversed and the same procedure followed as for the wire positive.

The limit of the voltage increase was in the region necessary to cause the corona to change over into the spark discharge.

IV. CHARACTERISTICS OF THE CORONA.

1. Positive Corona.

Most of the characteristics, forms and actions of the corona for the wire positive and the wire negative are quite different as has been shown by Peek, Schaffers and especially by Farwell.

It has been observed that the positive corona is quite stable and uniform in its optical properties, in its initial appearance and in its action upon the conductor on which it appears. Although the positive corona possesses these characteristics over quite a large range of voltages and pressures for the same temperature and air quality there is a region wherein this continuity fails. Fig. 3a shows one half the length of the typical close clinging gray haze discharge on the positive conductor. Below 130 m.m. of mercury pressure the typical positive glow will change in a second or two after the switch is closed to a much shorter and brighter glow. This collapse of the positive glow on the wire to a bright strip is accompanied by a luminous discharge on the disc which before had been without any visible light. On increasing the voltage the luminous strip on the positive wire takes its final form of a pennant and is directed toward the negative bead on the disc. The bead on the disc likewise changes with the increase of voltage, becoming brighter and accompanied by an isolated curved discharge as shown in Fig.

3b. The core of the pennant close to the wire is white, the region surrounding it and extending to its boundary is pink. The negative bead on the disc is a brilliant purple and its curved discharge is of a more or less brownish color.

The change in the nature of the positive corona is better shown when the wire is negative and the disc positive and for the same voltage and pressure as in the case described for the wire positive. The glow that covered the inner part of the hole in the disc, or inner circle, collapsed much in the same manner and in the same length of time as when on the wire, but instead of a pennant formation the discharge appears as isolated beads. These beads do not remain in a fixed position as the pennant did, but move around the periphery of the circle, following the motion of the negative bead on the wire.

An analogy to the motion followed by the negative bead on the wire and the positive beads on the disc may be shown on an apparatus for demonstrating simple harmonic motion, except that instead of the negative beads moving along the diameter of the circle as the positive beads travel the circumference, the negative bead is made to travel up and down an extended axis through the center of the circle. Fig. 4d shows an illustration of the motion of the beads for the wire negative, at a pressure of 75 millimeters. Since this pressure was found to give the most constant movement of the beads a photograph was taken. Fig. 4d was taken with the camera in-

clined toward the top face of the disc; hence, the elliptic path traced by the moving beads on travelling around the circle. The long strip shown at the center of the figure is one-half that traced by the motion of the negative bead travelling up and down on the wire.

If the voltage is increased very much above the point where the positive beads have their most rapid motion, they will group together and form a long narrow brush. The negative bead increases in length in proportion to the increase in voltage. Both bead and brush continue to move in the same manner as described for beads on both positive and negative conductors.

S. P. Farwell has previously observed the tendency of positive beads to form, but then only in the case of two parallel wires.

Farwell also noticed that an arc in series with the corona apparatus had a marked effect upon the character of the discharge, especially when the wire was positive.

When the voltage is sufficiently high to cause an arc to spring between the electrodes in the corona apparatus an arc of such a length that it is in an unstable condition, that is when it is hissing, is connected in series with the circuit, the corona with the wire positive takes the hazy ball form shown in Fig. 3c. The wire being surrounded by many intense purple points in the plane of the disc, and gray hazy ball discharge which seems to be in a state of rotation, the end of the rotating points terminating in the surface of the inner circle

Fig. 3a. 32 B & S copper wire; diameter, .02 cm.; pressure, 501 m.m.; volts, 9000; amperes, 310 x 10^{-}[illegible] ; wire positive.

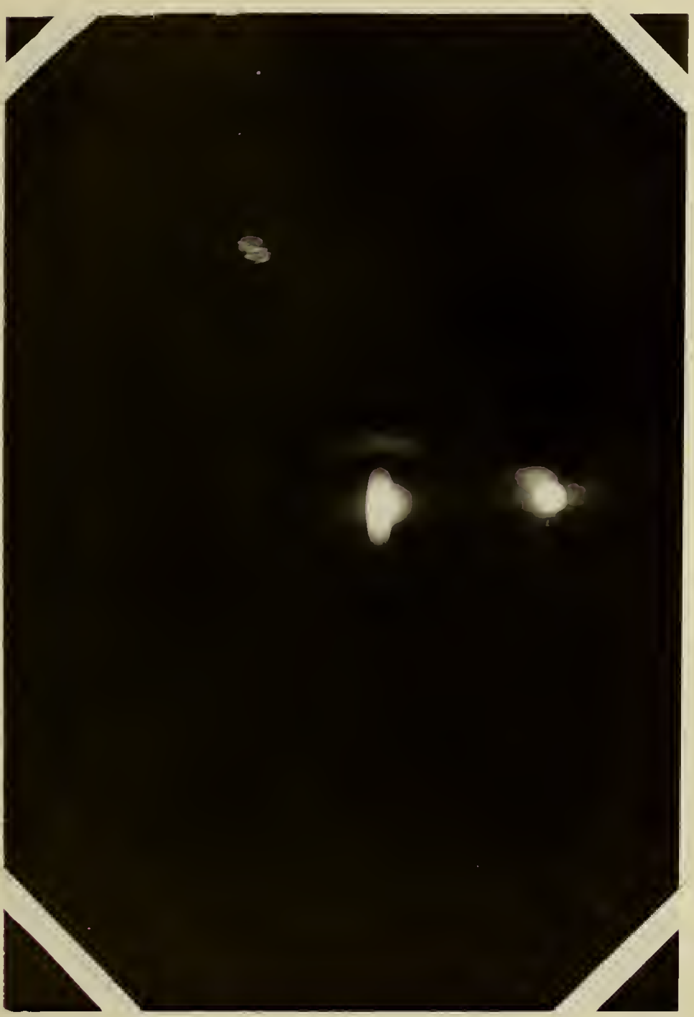

Fig. 3b. 32 B & S copper wire; diameter, .02 cm.; pressure, 75 m.m.; volts, 2675; amperes, 38×10^{-7}; wire positive.

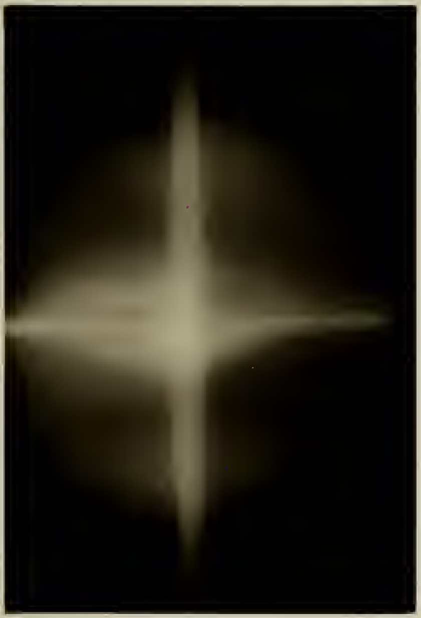

Fig. 3c. 32 B & S copper wire; diameter, .02 cm.; pressure, 501 m.m.; volts, 9600; amperes, 846 x 10^{-7} ; wire positive, arc in series.

in many bright beads. The wire is also seen to retain part of its close clinging discharge which protudes above and below the boundary of the ball. Fig. 4e shows the positive beads at 38 m.m. but they are fixed in position on the disc. Fig. 4f shows an arc between the positive disc and negative wire at 22 m.m. pressure.

2. Negative Corona.

The negative corona while less stable in its initial appearance, keeps its same general nature much more closely than the positive corona for all ranges of pressures and voltage. Fig. 4a, illustrates the unstable bead form of the starting of negative corona. This illustration was obtained for atmospheric pressure, 744 m.m. Fig. 4b shows the chacteristic nature of the negative corona at atmospheric pressure; a few well defined bright blue beads interspersed with the hazy unstable beads, besides the bead formation shown there is a faint positive glow in the inner circle of the disc. The beads shown on the negative wire in Fig. 4c are fan shaped, they remain fixed in position on the wire. The apex of the fan is on one side of the wire, it being an intense blue spot, the fan proper being made up of purplish streamers 2 or 3 m.m. long extending toward the disc. This bead formation on the wire will remain quite stable as long as the voltage is not high enough to cause the positive glow on the disc to collapse to the positive bead state as illustrated in Fig. 4d. It will be seen from Fig. 4b and Fig. 4c that the number of negative

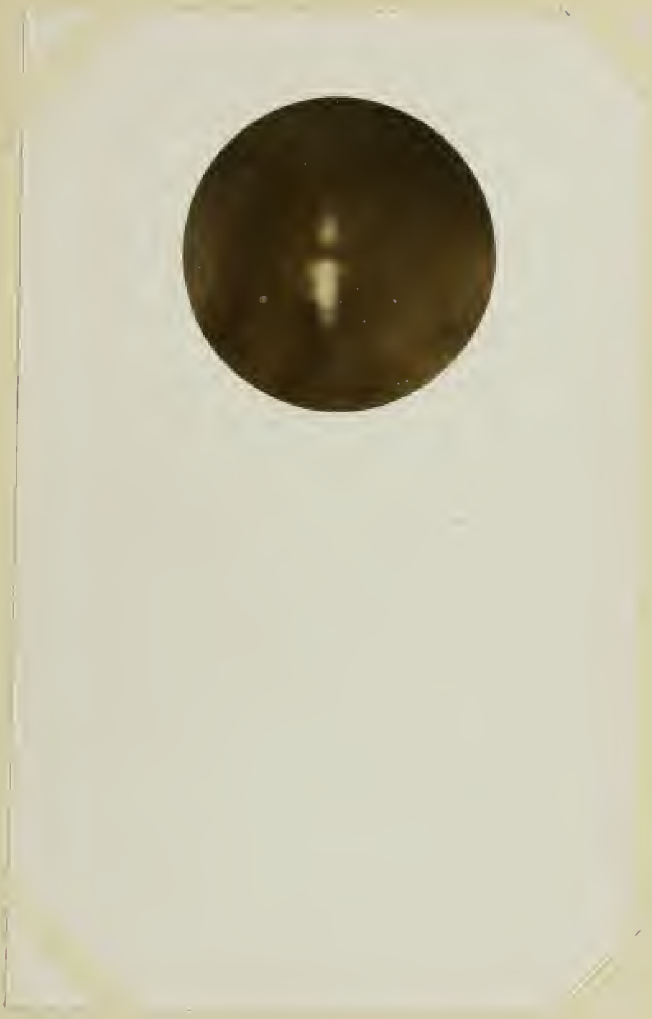

Fig. 4a. 32 B & S copper wire; diameter, .02 cm.; pressure, 744 m.m.; volts, 6900; wire negative.

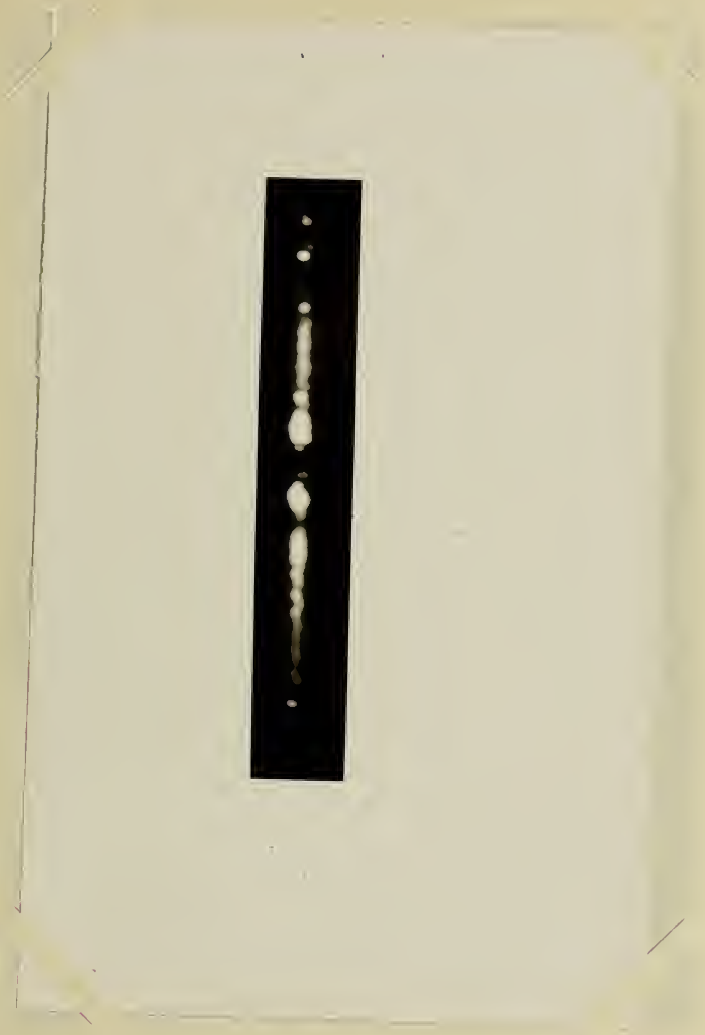

Fig. 4b. 32 B & S copper wire; diameter .02 cm.; pressure, 744 m.m.; volts, 10100; amperes, 37×10^{-7} ; wire negative.

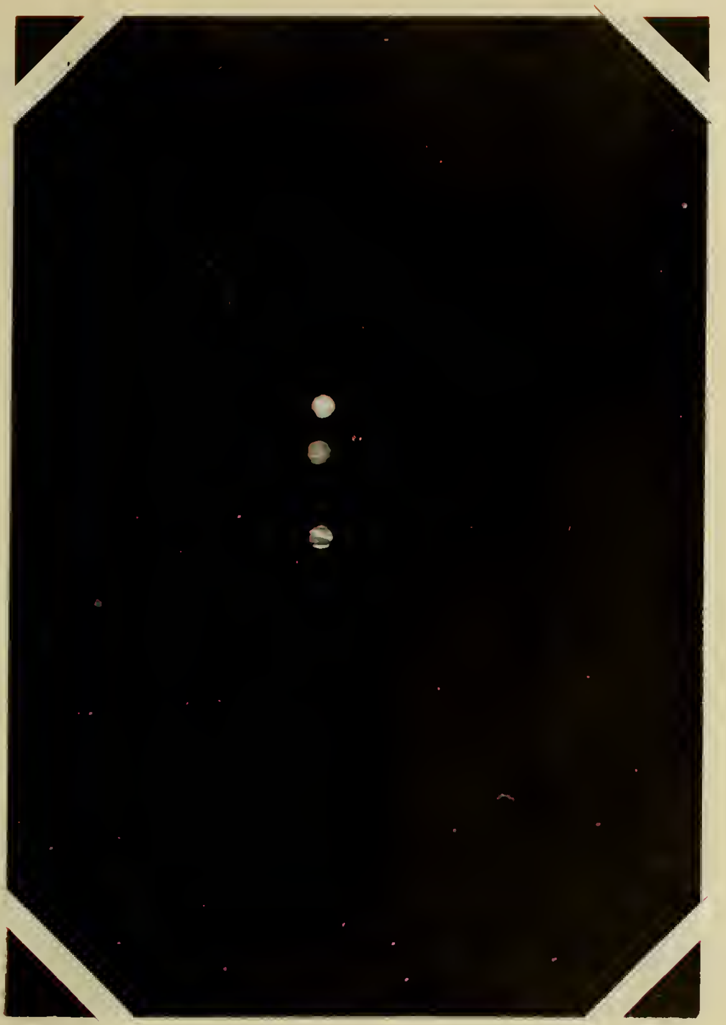

Fig. 4c. 32 B & S copper wire; diameter, .02 cm.; pressure, 501 m.m.; volts, 9100; amperes, 730×10^{-7}; wire negative.

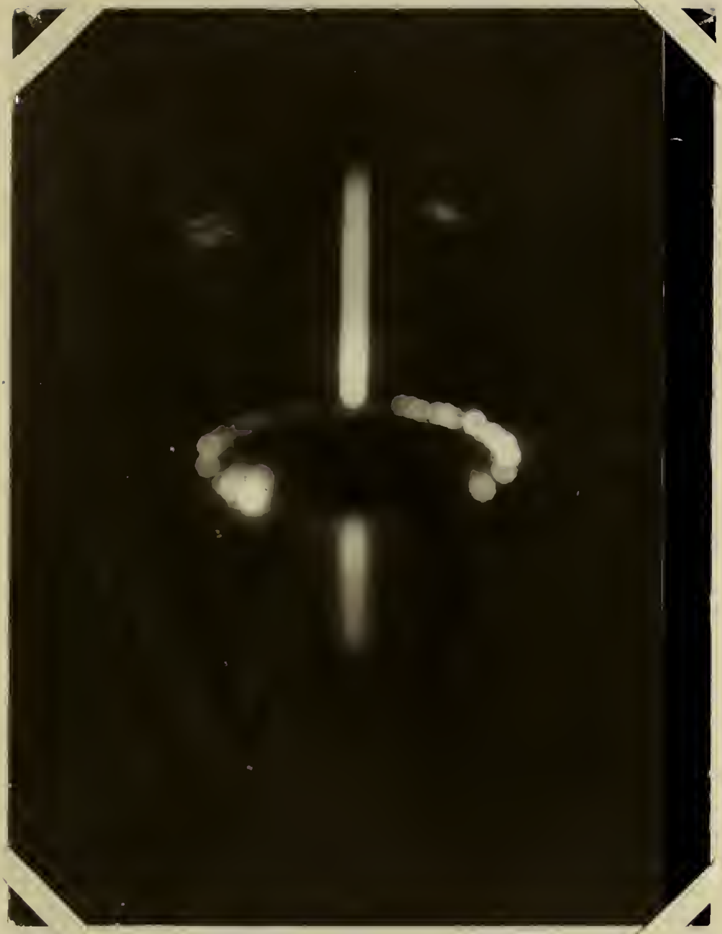

Fig. 4d. 32 B & S copper wire; diameter, .02 cm.; pressure, 75 m.m.; volts, 2675; amperes, 46 x 10^{-7} ; wire negative.

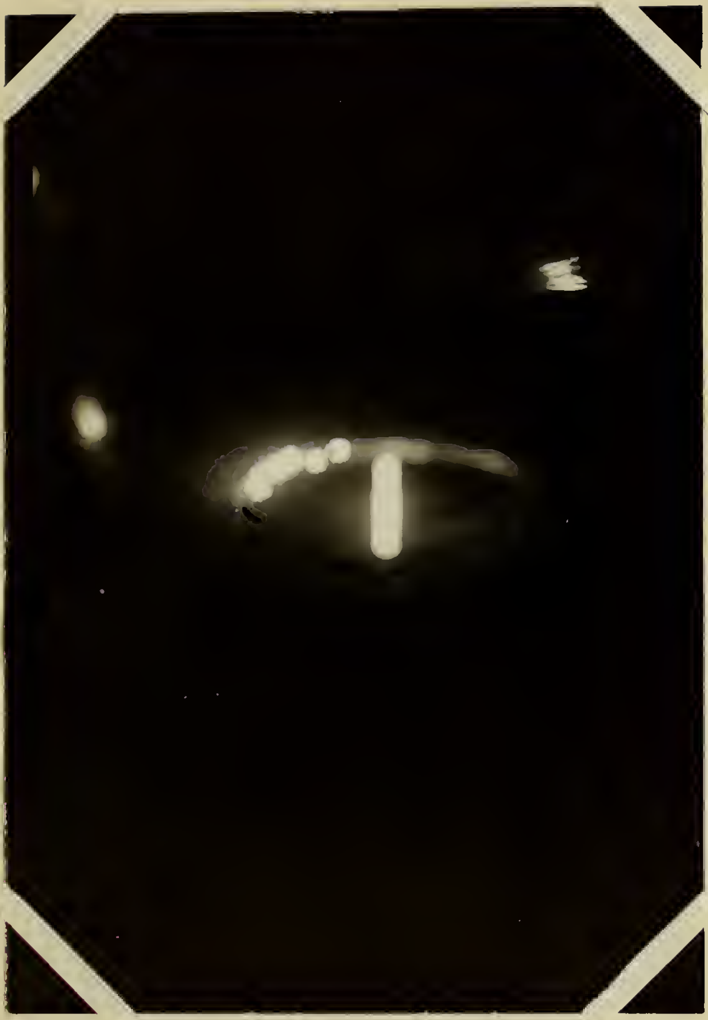

Fig. 4e. 32 B & S copper wire; diameter, .02 cm.; pressure, 38 m.m.; volts, 2000; wire negative.

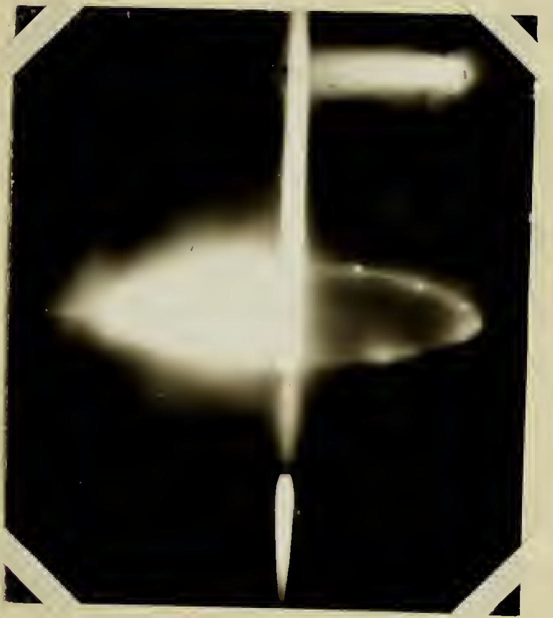

Fig. 4f. 32 B & S copper wire; diameter, .02 cm.; pressure, 22 m.m.; volts, 2300; wire negative.

beads is probably some function of the pressure and voltage as has been pointed out by Mr. Farwell in his work. And so too, it is probable that the number of positive beads as shown in Figs. 4d and 4e are a function of the pressure and voltage.

V. DISCUSSION OF THE CHARACTERISTIC CURVES

Two sets of curves were plotted from the data as given in Tables 6, 7, 8 and 9.

The first set, Fig. 5, illustrates the difference in the starting voltages for the corona, with the wire positive and with the wire negative as a function of the pressure.

This set of curves is for a copper wire .02 cm. in diameter. It will be seen that the curve for the wire positive and the curve for the wire negative cross at about 130 m.m. pressure. This crossing has also been observed by Farwell, but he leaves some doubt as to the existance of the phenomena. Since the diameter of wire that Farwell used in obtaining his curves was .041 cm., and the similarity of the shape of the curve he obtained, to the curve obtained in this investigation for a smaller size wire; points to the fact that the crossing point for the curve with the wire positive and then negative, is dependent not only on the pressure but also on the diameter of the wire.

The second set of curves, Figs. 6, 7, 8, and 9 are characteristic curves giving the relation between potential difference and current. For the lowest pressures, 75 m.m. the curves do not cross each other, and the current for the wire negative at a given voltage is always larger than the current for the wire positive.

At 254 m.m. pressure the two curves start at approximately the same voltage and have about the same value of current. At 501 m.m. pressure the two curves cross, for the lower voltages the negative current being smaller than the positive current, but for higher voltages the current for the wire negative is the greatest. The same crossing is noticed for atmospheric pressure 744 m.m.

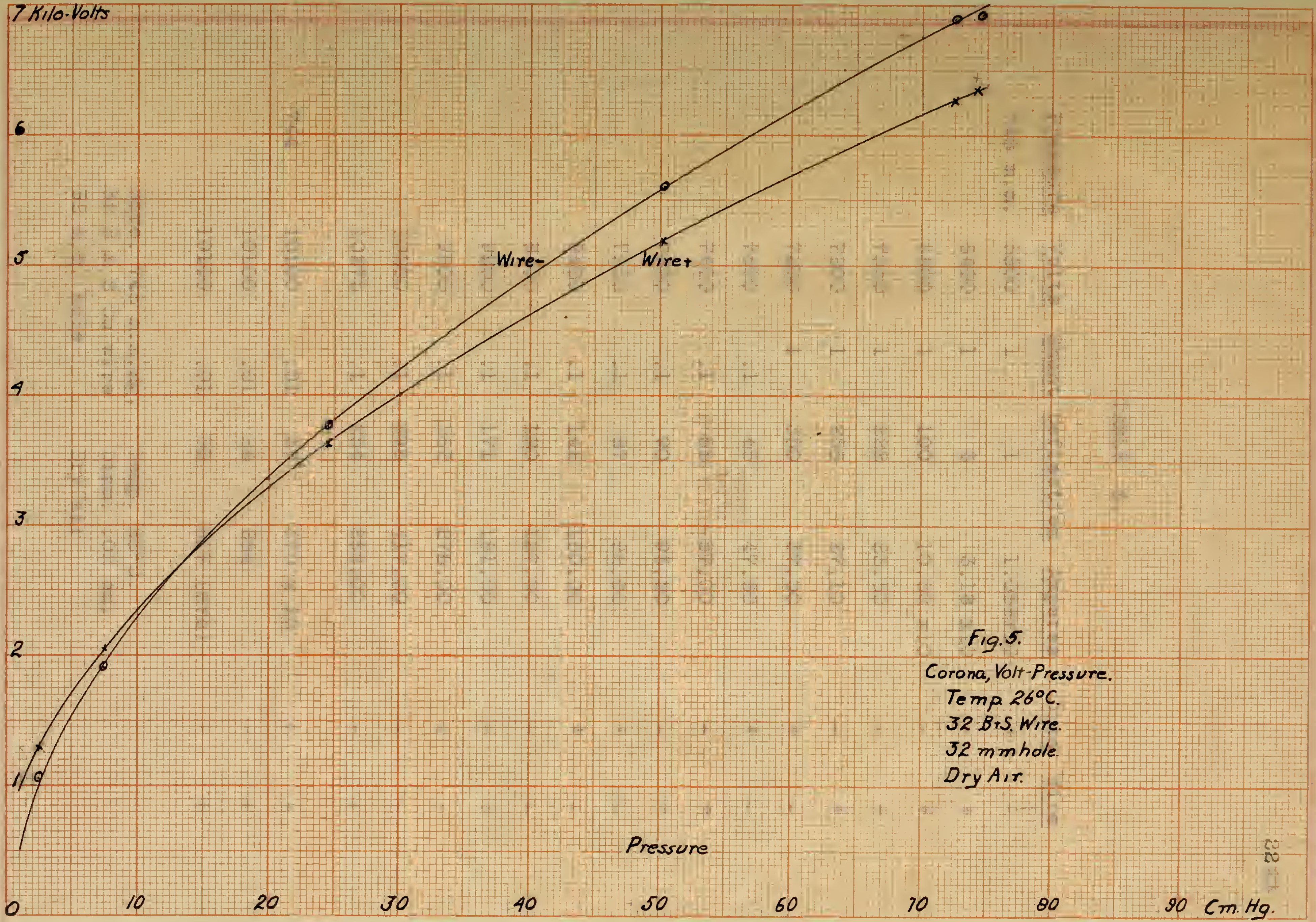

Fig. 5.

Corona, Volt-Pressure.
Temp. 26°C.
32 B+S. Wire.
32 mm hole.
Dry Air.

TABLE 6.

Pressure	Volts	Shunt	Deflection	Amperes	Disc	Wire
748 m.m.	5800	1	1	1.058x10	+	-
	6400	1	3	3.18 x10	-	+
	6800	1	100	10.58 x10	-	+
	7050	1	222	23.50	-	+
	7200	1	256	27.10	-	+
	7200	1	350	37.00	+	-
	7600	.1	45	47.60	+	-
	7450	.1	55	57.00	-	+
	7950	.1	90	95.20	-	+
	7950	.1	87	92.00	+	-
	8400	.1	142	150.00	+	-
	8400	.1	120	127.00	-	+
	9200	.1	171	181.00	-	+
	9200	.1	263	278.00	+	-
	10200	.1	395	417.00	+	-
	10275	.1	254	268.00	-	+
744	10100	.01	36	370 x 10	+	-
	10100	.01	24	254	-	+
	10100	.01	30	317 (arc)	-	+

Baro. 748 m.m.Hg.   Temp. 26° C.
32 B & S Cu wire   Diam. .02 cm.
32 m.m. hole   Dry air

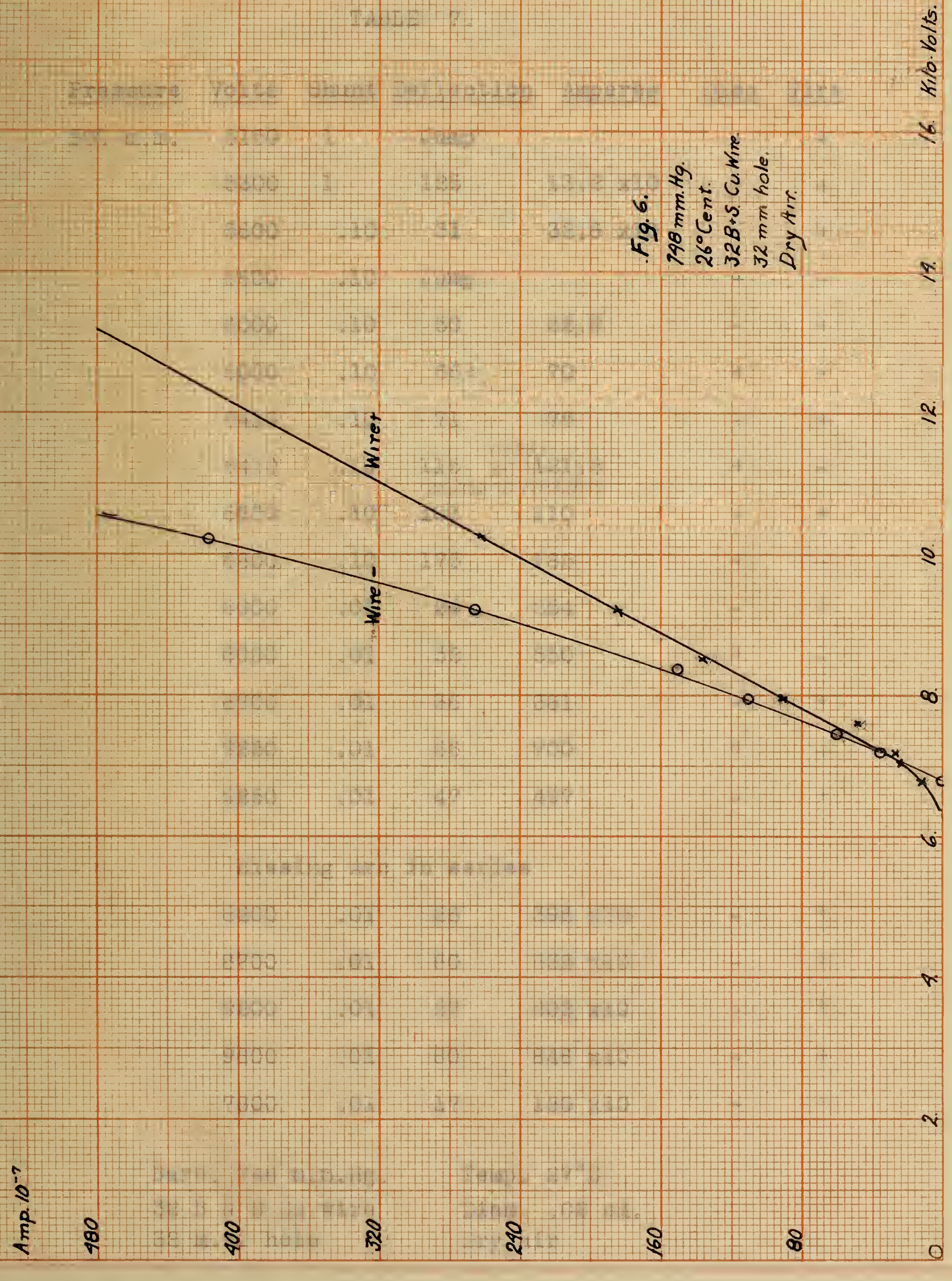

Fig. 6.
748 mm. Hg.
26°Cent.
32 B+S. Cu Wire.
32 mm hole.
Dry Air.

TABLE 7.

Pressure	Volts	Shunt	Deflection	Amperes	Disc	Wire
501 m.m.	5150	1	Jump		-	+
	5300	1	125	13.2 x10	-	+
	5600	.10	31	32.8 x10	-	+
	5600	.10	Jump		+	-
	6000	.10	50	52.9	-	+
	6000	.10	66+	70	+	-
	6410	.10	71	75	-	+
	6410	.10	115	121.5	+	-
	6800	.10	103	110	-	+
	6800	.10	175	185	+	-
	8000	.01	24	254	-	+
	8000	.01	52	550	+	-
	8700	.01	36	381	-	+
	9250	.01	66	700	+	-
	9250	.01	47	497	-	+
	Hissing Arc in series					
	8200	.01	28	396 x10	-	+
	8700	.01	60	635 x10	-	+
	9200	.01	57	602 x10	-	+
	9600	.01	80	846 x10	-	+
	7800	.01	17	180 x10	-	+

Baro. 748 m.m.Hg.   Temp. 27°C
32 B & S Cu.wire   Diam. .02 cm.
32 m.m. hole   Dry air

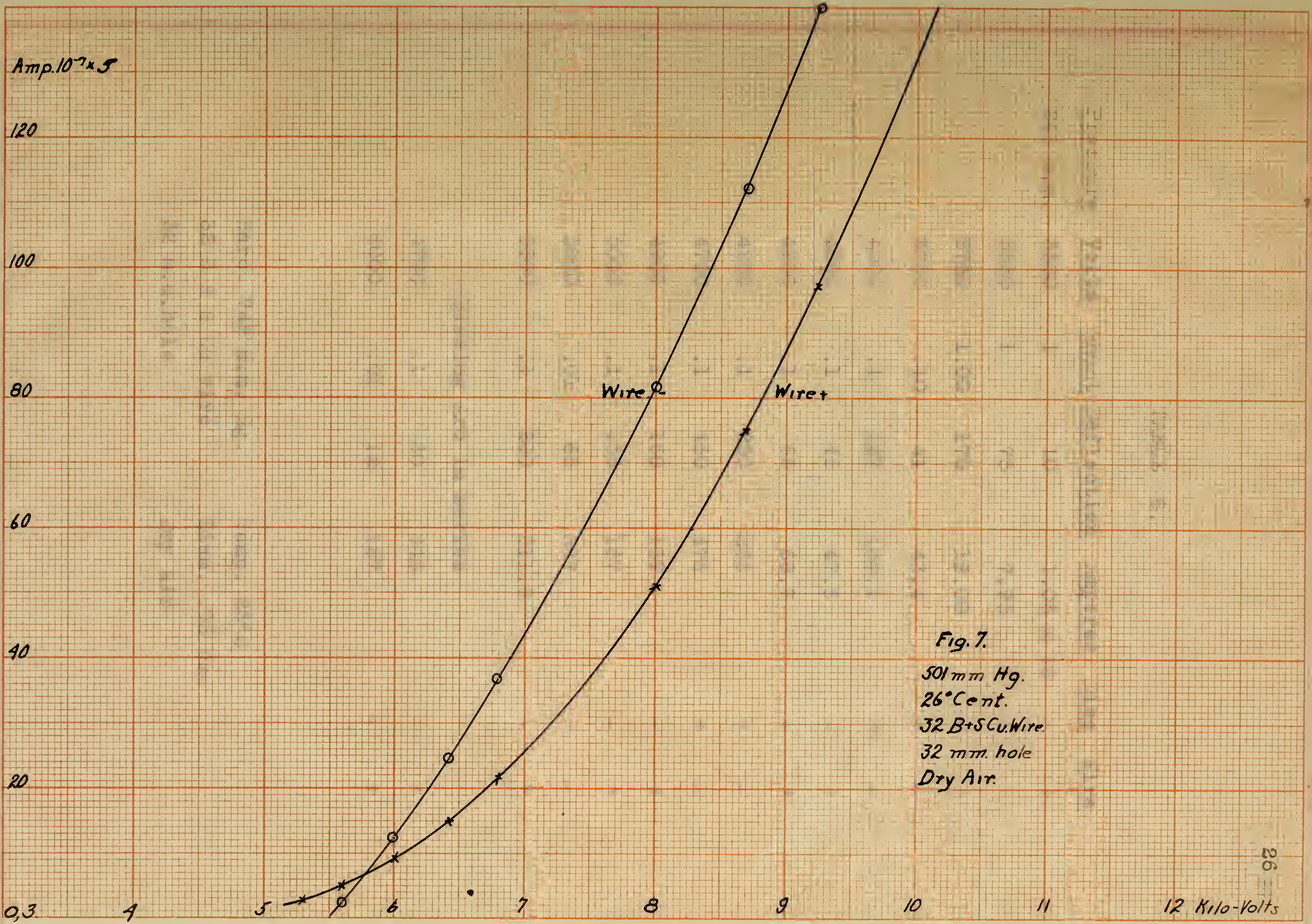

Fig. 7.

501 mm Hg.
26°Cent.
32 B+S Cu.Wire.
32 mm. hole
Dry Air.

TABLE 8.

Pressure	Volts	Shunt	Deflection	Amperes	Disc	Wire
245 m.m.	3500	1	10	1.05 x 10	-	+
	3550	1	75	7.95	-	+
	3750	1.00	170	18.00	-	+
	3750	.10	41	43.4	+	-
	4000	.1	127	134.1	+	-
	4000	.1	45	47.6	-	+
	4250	.1	65	68.7	-	+
	4250	.1	250	265	+	-
	4700	.1	450	476	+	-
	4900	.1	150	159	-	+
	5000	.1	158	167	-	+
	5000	.01	65	687	+	-
	5300	.1	200	211.8	-	+
		Hissing Arc in series				
	4700	.1	80	845	-	+
	6000	.01	12	127	-	+

Baro. 748 m.m. Hg. Temp. 26° C

32 B & S Cu.wire Diam. .02 cm.

32 m.m.hole Dry air

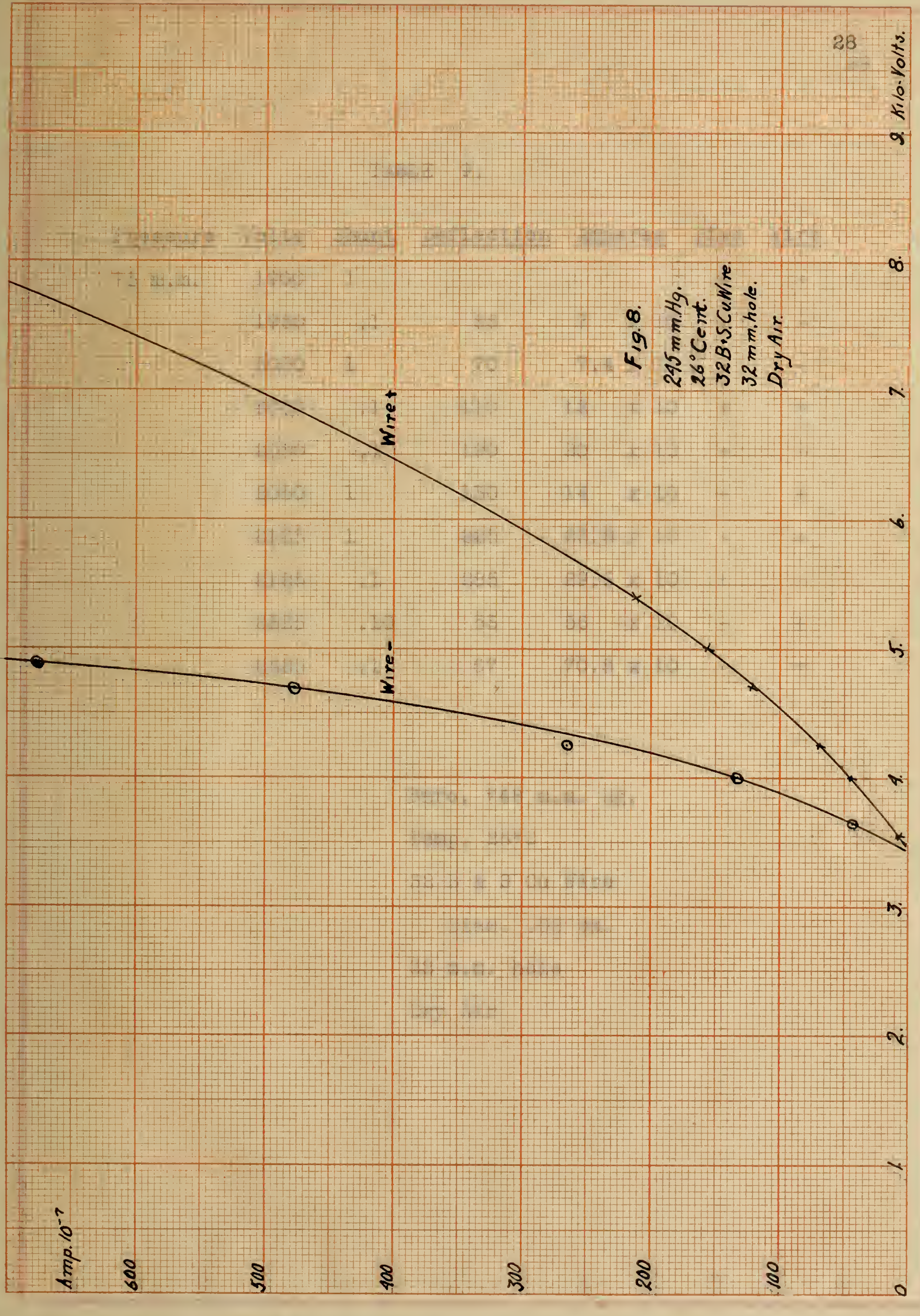

Fig. 8.

295 mm. Hg.
26° Cent.
32 B.&S. Cu. Wire.
32 mm. hole.
Dry Air.

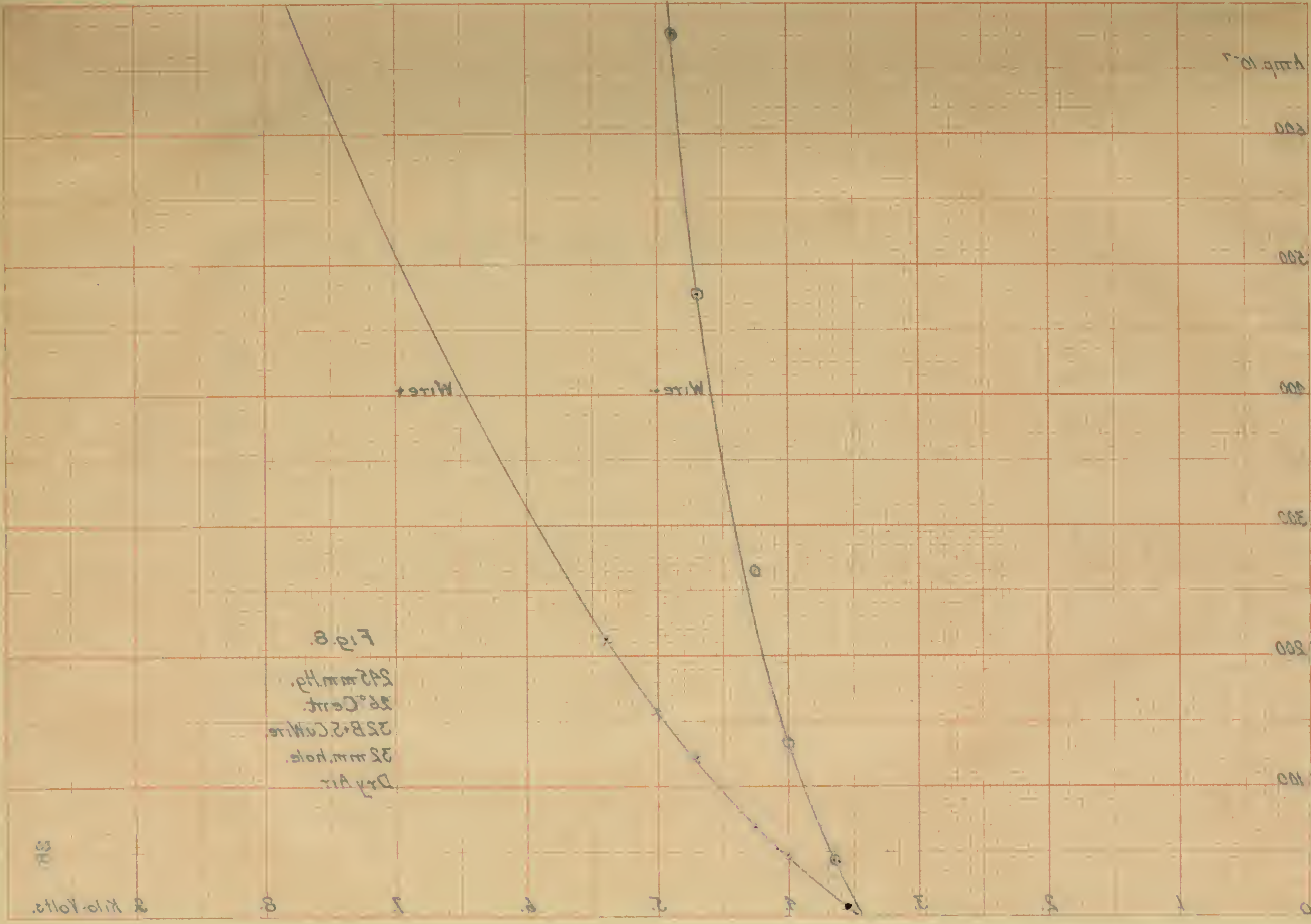

Fig. 8.

245 mm Hg.
26°Cent.
32 B+S. Cu Wire.
32 mm hole.
Dry Air.

TABLE 9.

Pressure	Volts	Shunt	Deflection	Amperes	Disc	Wire
75 m.m.	1900	1			-	+
	1950	.1	66	7 x 10	+	-
	2000	1	70	7.4 x 10	-	+
	2000	.1	110	12 x 10	+	-
	2050	.1	190	20 x 10	+	-
	2050	1	130	14 x 10	-	+
	2125	1	225	23.8 x 10	-	+
	2125	.1	285	29.6 x 10	+	-
	2325	.10	53	56 x 10	-	+
	2425	.1	67	70.8 x 10	-	+

Baro, 748 m.m. Hg.

Temp. 26°C

32 B & S Cu Wire

Diam. .02 cm.

32 m.m. hole

Dry Air

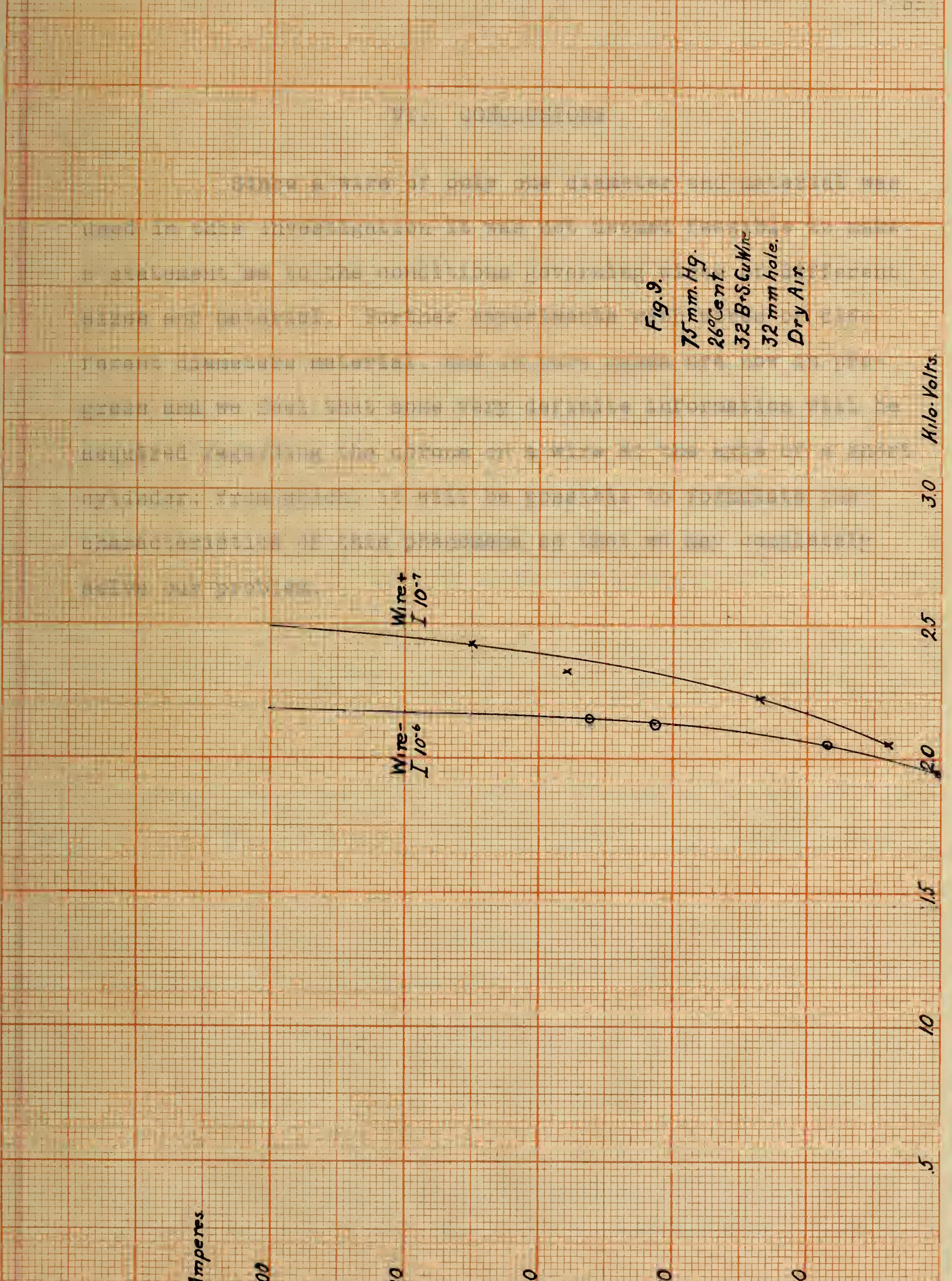

Fig. 9.

75 mm. Hg.
26°Cent.
32 B+S. Cu. Wire
32 mm hole.
Dry Air.

VI. CONCLUSIONS

Since a wire of only one diameter and material was used in this investigation it was not deemed feasible to make a statement as to the conditions governing wires of different sizes and material. Further experiments with wires of different diameters material, and in pure gases are now in progress and we feel that some very definite information will be acquired regarding the corona on a wire at the axis of a short cylinder; from which, it will be possible to formulate the characteristics of this phenomena so that we may completely solve our problem.

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